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THE NASA SCHEDULING SYSTEM

Scheduling in Project Management

Scheduling in project management is comparable to scheduling in other forms of management in at least one respect. It involves determining a course of action or plan over time to accomplish a task subject to numerous constraints. Modification of the time allowed takes place as new constraints arise or existing ones become less constraining.

In the Apollo program an example of a long-range time constraint is the commitment to land men on the moon and return them safely to Earth before 1970. This schedule decision paced the entire program from its inception until its successful accomplishment in July, 1969.

Shorter range schedules which are of a pacing nature have fixed constraints based on lunar windows, those brief periods each month during which a launch can be made to go to the moon. Should one of these time slots be missed due to schedule slippage, then a delay of at least one month will be required. If a series of launches are scheduled, the entire sequence may have to be slipped if a lunar window is missed.

The cases above represent major schedule determinants in that they are set by presidential decision backed up by Congress and astronomical events respectively. Most schedule constraints however can be manipulated by program and project managers. As discussed in Working Paper 10, the authority to change these constraints rests with a variety of individuals. The most significant change authority being reserved for OMSF personnel at Headquarters.

As the program managers, project managers, and contractor personnel seek to establish or modify schedules, one of the major factors to be considered is the tradeoff among the three primary measures of effectiveness of project management; schedule performance, cost performance, and technical performance.

"General Samuel C. Phillips, the Apollo Program Director, has stated that, Program Management...in the final analysis...(is) doing what you said you would do.' To accomplish this within defined program goals and parameters, a plan with measurable

milestones is developed, a commitment is made to those milestones, and then the job is done. More specifically, Program Management is assuring that an organization meets its program goals, within defined performance specifications, costs, and schedules."¹

Relationships of Cost, Schedules, and Technical Performance

In the management of projects three measures of effectiveness are commonly utilized based on three fundamental questions pertaining to any project task:

1. What is the task to be accomplished?
2. When is the task to be completed?
3. How much should the task require in terms of resources?

The first of these questions is answered through the establishment of technical objectives which are first defined broadly and then reduced to smaller and smaller technical tasks. The measure of managerial effectiveness related to this question is the level of technical performance to be achieved.

The second question is answered through the establishment of schedules which define a time line along which the project progresses. The measure of managerial effectiveness related to this question is the degree to which schedules are being met.

The third question concerning resource requirements is commonly specified in terms of dollars or manpower. Although ideally the resource requirements should be stated and controlled directly according to the specific requirements of the task, this is difficult to achieve in complex projects. For example, in launching a simple sky rocket the requirements include one skyrocket, one match, and one person to set up and light the skyrocket. These represent specific statements of resources.

In the launching of a Saturn V, however, millions of objects are required and they must be designed, fabricated, assembled, tested, and operated by hundreds of thousands of individuals with widely divergent skills. It is impossible for a top management group to maintain visibility on resource requirements and resources utilization in terms of

¹ Apollo Program Management, Vol. 4 Kennedy Space Center, Program Control Office, APO, KSC 130-12-0001, 1/15/68, pp. 2-1.

these physical objects and individual people. Therefore the approach taken in Apollo and other large, complex projects is to plan and control resources in terms of aggregate units, dollars and manpower, which tend to homogenize the individual differences in objects and people required. These aggregate measures provide a measure of managerial effectiveness based on cost and manpower performance.

The test of efficient managerial performance rests on these three measures: technical performance, schedule performance, and cost performance. Each of them affects or is affected by the others. To achieve technical performance it is clear that sufficient resources must be available (expressed in dollars and manpower) and that sufficient time be allowed to complete the task. Although plans provide some measure of the cost and schedule estimates, these two factors are also constraints on performance. Without budget constraints or time constraints it would be much simpler for project managers to complete their tasks. Indeed the question arises whether there even needs to be a manager under such circumstances. The test of effective management rests on the ability of the managerial team to achieve the tasks assigned within such constraints.

Without a cost constraint a typical R & D project will progress in such a manner that the technical requirements become paramount. An engineer or scientist is trained and committed to developing hardware which works with little regard for cost or schedule. Considering this background his tendency will be to design into the hardware foolproof mechanisms made of the best materials available...a practice referred to in the profession as goldplating. In addition to goldplating, there is a tendency to continue to improve the hardware. (Once something is designed, fabricated, assembled, and tested, the results will lead to new innovations in design resulting from the experience gained in transforming it from an idea to an operating and tested device. This tendency to avoid "locking up the black box" would go on for long periods of time without cost and schedule constraints.

Technical performance is also related to scheduling in another way. In typical manufacturing operations in industry it has been found that a given product can be

manufactured in an optimum manner which can be measured through time study which provides specific time standards. In project management in R&D such time standards are rare due to the uncertainties inherent in the R&D environment where much work is carried out at the fringe of the state of the art. Yet without schedules as a constraint on technical performance it is likely that a program will stretch out over an inordinate amount of time.

The stretch out of the project, although it may increase the probability of successful technical accomplishment, usually will increase the costs and also create numerous problems where hardware items interface. A delay in the acquisition of one item may delay the entire project resulting in significant amounts of idle resources while people wait for the needed part.

On the other hand, crashing a schedule by severely reducing the time allowed also will result in increased costs and may reduce the probability of successful technical performance. In project management, therefore, the schedule must be set at the outset and adjusted periodically (due to the uncertainties in R&D) to guard against the need for crashing the project or to avoid project stretchouts. Both of these conditions can increase costs considerably and may, in some cases, impair technical performance.

In general, a delicate balance must be struck among technical requirements, the time allowed, and the resources committed to a project. If the technical requirements are too high or if they change too often, cost performance and schedule performance will suffer. If insufficient resources are allocated the technical performance may be impaired and there will be a tendency to stretch out the project which may result in higher costs at the end of the project. If the schedule is too tight performance may suffer and costs will be significantly increased. If the schedule is too loose procrastination and technical changes will occur creating disequilibrium in the balance of systems and costs will increase due to the stretchout.

In achieving the balance among cost, schedule, and technical performance in project management it is common to find all three in a state of continual adjustment as the project proceeds through its life cycle. If a technical glitch develops, it

becomes necessary to modify the schedule and resources required to overcome it. In other cases a particular item may be delayed and become the pacing item for the project. Some NASA personnel refer to this as "the long pole in the tent" presumably because it holds everything else up. In such a case a workaround may be necessary to recover the lost time through reallocation of resources.

A NASA publication discusses this condition with respect to schedules as follows: "These (schedule) milestones, however, are not so inflexible as to be irrevocable. They represent guidelines which are in a sense negotiable, provided the next higher level milestone is not endangered. It is realized that an installation or test sequence, for example, can be accomplished in more ways than that which is considered ideal. Since these milestones are established well in advance of the actual activity, they are normally representative of an ideal work flow. During the actual performance of the planned work, however, circumstances may prevent the accomplishment of the planned objective on the original schedule. The milestone, therefore, is "worked around" and accomplished at a later date. These workarounds are a true indication of management in action."²

Providing managers with visibility of the variety of changes taking place requires an elaborate information system, especially in a project as complex and large as Apollo. The primary objectives of the Apollo information system include:

- a. Keeping management informed on a day-to-day basis of cost, performance, and schedule status of the Apollo Program.
- b. Isolating management problems in terms of cost, schedule, and technical performance.
- c. Providing early warning of potential management problems which may have an adverse effect on schedules, cost, or performance.
- d. Establishing criteria for developing and implementing workaround plans.
- e. Providing a form for the exchange of management information.

² Ibid., p. 4-53.

- f. Promoting management discipline and teamwork throughout the Apollo organization."³

In order to meet these objectives a number of key document flows are required. We shall trace these flows with special emphasis on scheduling in the Apollo Program.

The Key Document Flows

The focus on cost, schedule, and technical performance is depicted in Figure 1 "The Flow of Information for Decisions Considering All Variables for Programs." Contractor reports, of course, are inputs to all three variables and represent the level of input closest to the actual work being performed. In addition, other management systems have been developed by NASA to track and monitor performance in the areas of cost, schedule, and technical performance.

The key document flows required to meet these three measures of performance vary according to the areas, however they all are related to two important documents, the Apollo Project Approval Document (PAD) and the Apollo Program Development Plan (PDP).

The Apollo Project Approval Document (PAD)

The PAD is divided into ten sections dealing with the following subjects:⁴

1. Identification of the program.
2. Designation of project titles and code numbers.
3. A statement of broad objectives of the program.
4. The technical plan which describes the test plan, system description, operations and requirements as well as facilities required.
5. The major support interfaces.
6. Procurement approval indicating the contractors and centers responsible for major items.

³ NASA-Apollo Program Management Vol. 1, December 1967, Apollo Program Office, NASA p. 4-31.

⁴ Apollo Project Approval Document, NASA PT 1969.

THE FLOW OF INFORMATION
FOR DECISIONS
CONSIDERING ALL VARIABLES
FOR PROGRAMS

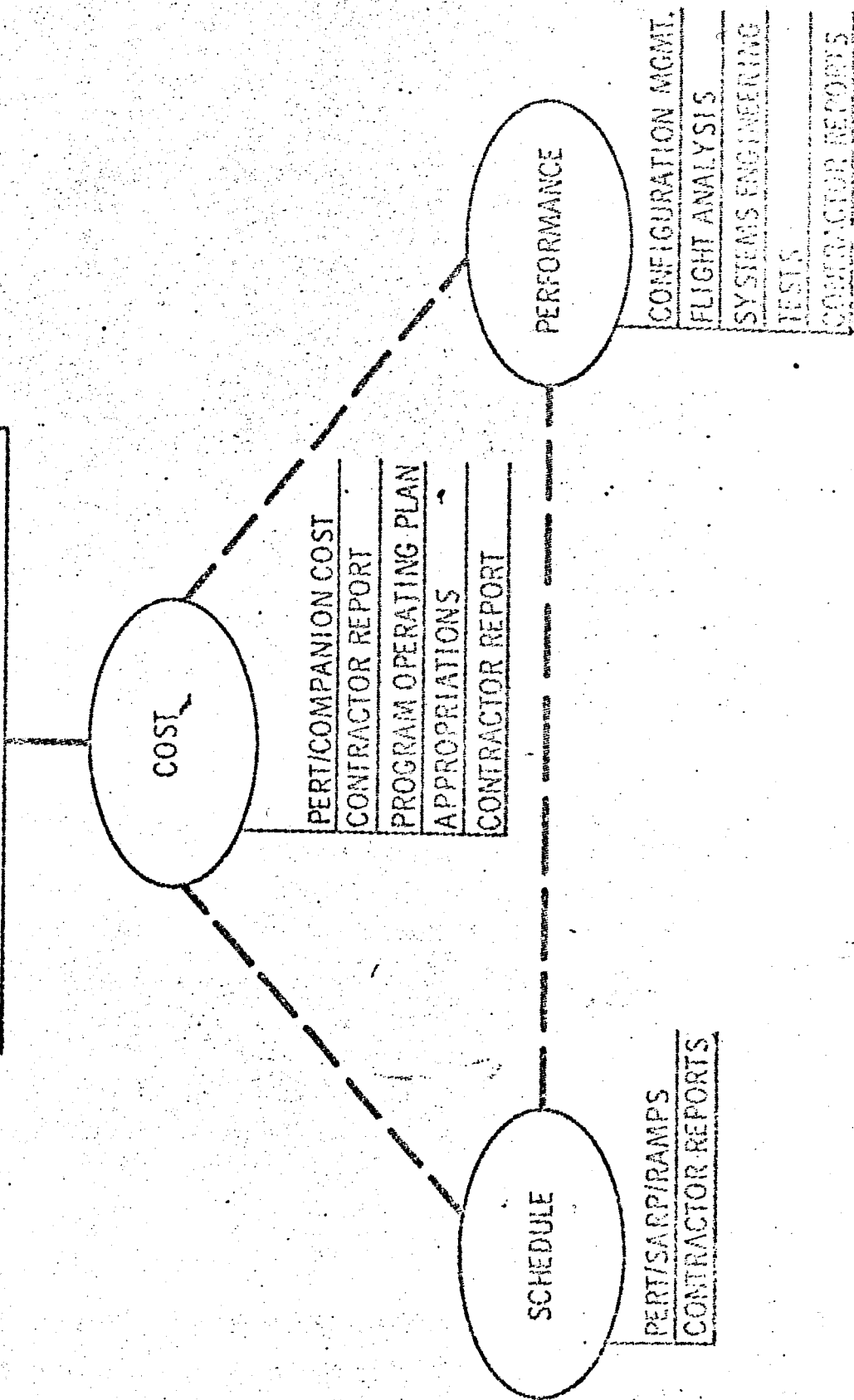


Figure 1

7. Schedules indicating major flight development phasing, launch dates and future major technical and management decision points.
8. Resources including both planned and approved resources for the program.
9. Management covering the organizational assignments for program tasks.
10. Controlled items. Of interest in this paper are the official NASA Flight Schedules (to the month in the current year, to the nearest quarter for the next year, and by year thereafter).

The PAD provides the overall authority to continue Apollo Program activities for the fiscal year. It represents, in terms of scheduling a starting point for more detailed decisions as it covers the Apollo Launch Schedule and the Apollo Launch Readiness Schedule.⁵

Once the schedule objectives are established in the aggregate in the PAD and authority to proceed on that schedule is given by the sign off of the PAD, the next key document which bears on program planning and scheduling is the Apollo Program Development Plan or FDP.

Apollo Program Development Plan (FDP)

The FDP identifies "program requirements, responsibilities, tasks, resources and time phasing of major actions required to accomplish the objectives of the Apollo Program."⁶ This development plan provides a single, authoritative summary document which:

- Delineates the manner in which the objectives of the Apollo Program, as defined in the current Project Approval Document, shall be achieved;
- Becomes the primary decision and approval documentation and baseline of the Apollo Program for the evaluation of program performance and program changes;

⁵ Ibid., Attachment B

⁶ Apollo Program Development Plan, M-D MA 500 MA 001.000-1 Apollo Program Office, OMSF, NASA, Washington, D.C., January 1, 1966.

- Becomes the basic guidance and directive instrument to participating organizations for implementation of approved program changes."⁷

Although the Project Approval Document is issued annually, the Program Development Plan is published in January and July. As it is more detailed than the PAD, the PDP may also be modified as key decisions are made throughout the year or when major program changes are made. These modifications are transmitted to managers through Program Directives which carry authority similar to that of the PDP. One of the key directives in terms of schedules is Apollo Program Directive 4.

The PDP is composed of 17 sections as follows:

1. Program Management
2. Schedules
3. Procurement Management
4. Data Management
5. Configuration Management
6. Logistics
7. Facilities
8. Fund and Manpower Requirements
9. Technical Description and System Engineering
10. Reliability and Quality Assurance
11. Safety
12. Test Program
13. Activation of Launch Site Facilities and Equipment
14. Mission Operations
15. Mission Training
16. Related Programs
17. Advanced Missions

Although these seventeen sections cover the plans and by implication the controls

⁷ Ibid., p. 9.

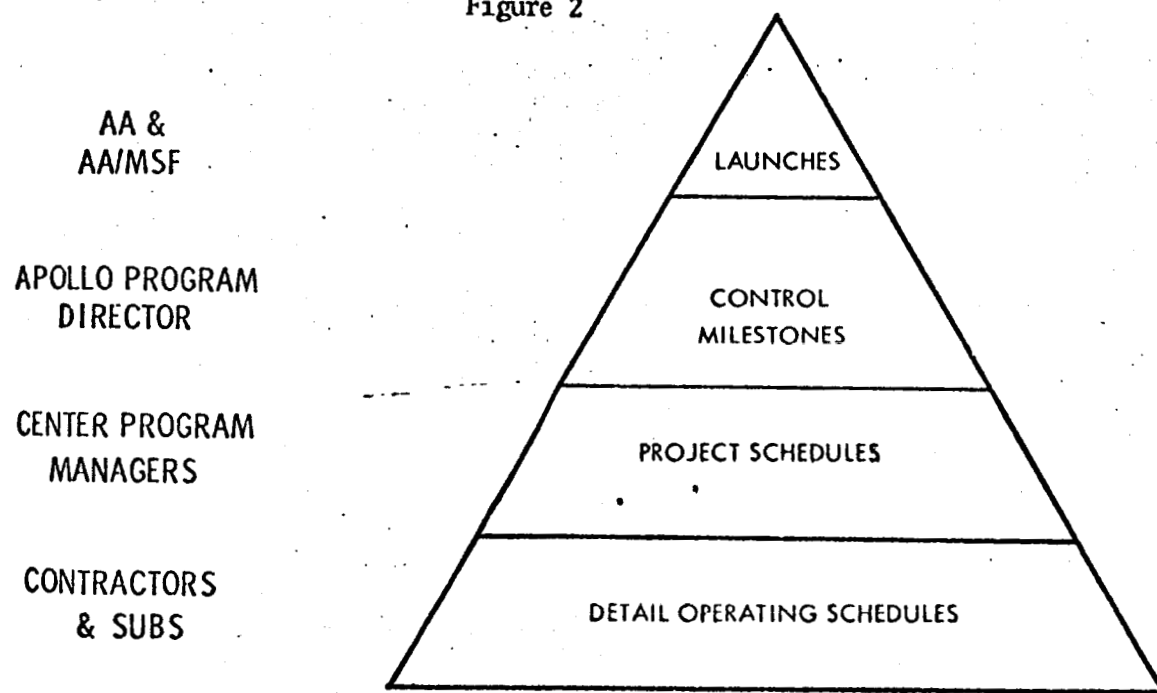
to be used by managers in running the program and its subsidiary projects, the area of concern in this paper is the scheduling system and our discussion will center only on that.

"To achieve the established missions and objectives of the Apollo Program, it is essential that all program effort be undertaken on the basis of approved schedules. In addition, it is important that there be a continuing review process by which potential problems can be identified, assessed, and channeled to the proper decision making level. To this end, the Apollo Program Office maintains a schedule system to reflect the current approved schedules and the status of effort against these schedules. Further, monthly Program Reviews are held to evaluate progress and to determine corrective actions as required."⁸

The schedules developed for the program range from overall schedules for launches to detailed operating schedules. The basis for approving these schedules is hierarchical within the organizations involved as depicted in Figure 2. The launch schedules are developed and authorized by the Associate Administrator of NASA and the Associate Administrator for Manned Space Flight. The development of schedules for controlled milestones rests with the Apollo Program Director and his Apollo Program Control group. The more detailed schedules for particular projects within the Apollo Program are developed and authorized by the Center Program Managers who may delegate this authority to their project managers. Finally, the detailed operating schedules are developed by the contractors and subcontractors who are providing the hardware and software.

Figure 3 depicts the Apollo Schedule System Flow. At the top level, NASA as an agency develops the Project Approval Document and along with it the Official NASA Flight Schedule. At the next lower level, the Office of Manned Space Flight, The Apollo Program Development Plan is created and concurrent with it the Schedule Summary. At the next level within OMSF is the development of schedules for controlled milestones under APD through the use of APD-4, the program directive series covering schedules. At the field centers, (RSC, MSFC, and MSC) detailed project schedules are developed

Figure 2



CONTROL LEVELS FOR APOLLO SCHEDULES

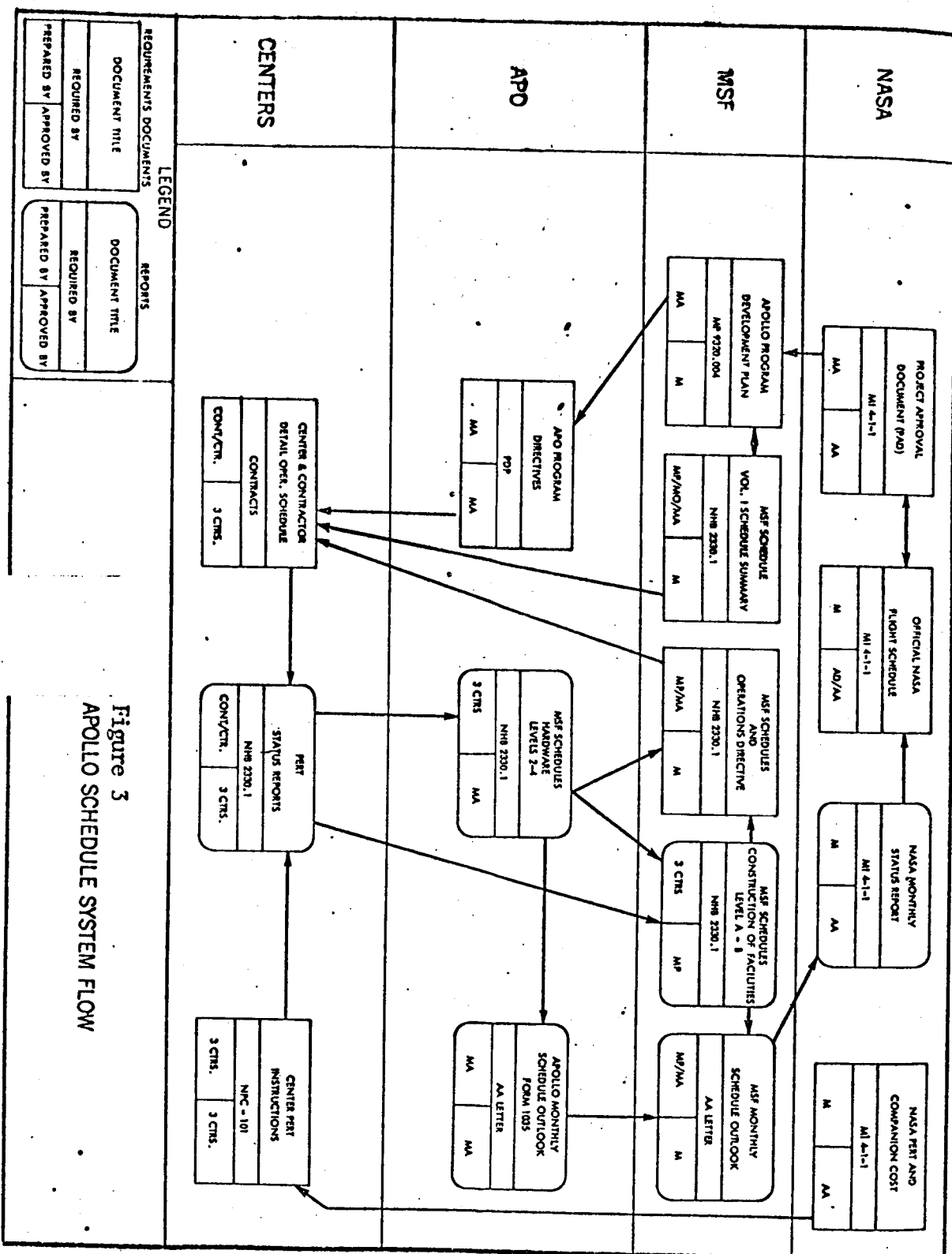


Figure 3
APOLLO SCHEDULE SYSTEM FLOW

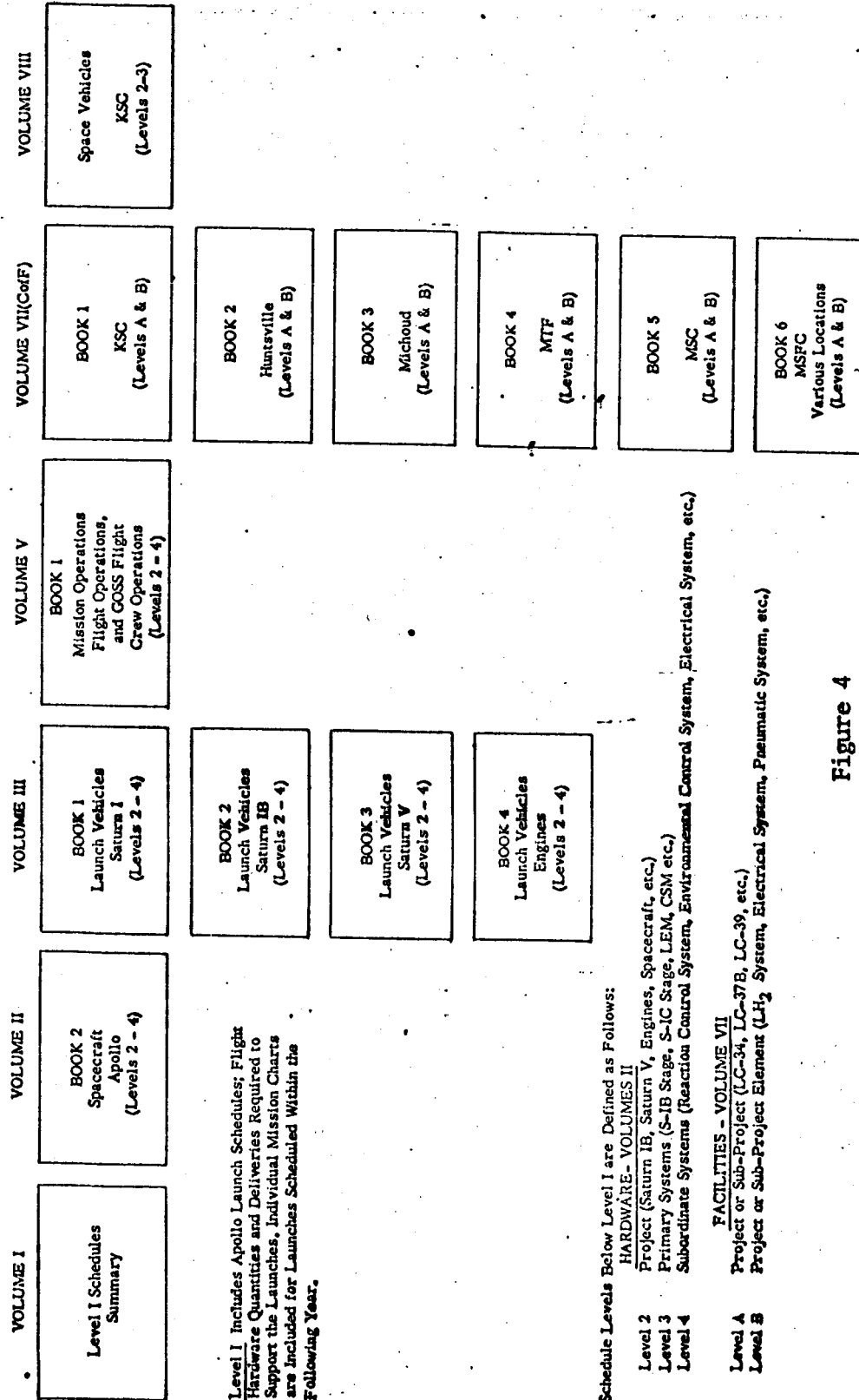


Figure 4

Manned Space Flight Schedules Document Volumes and Levels

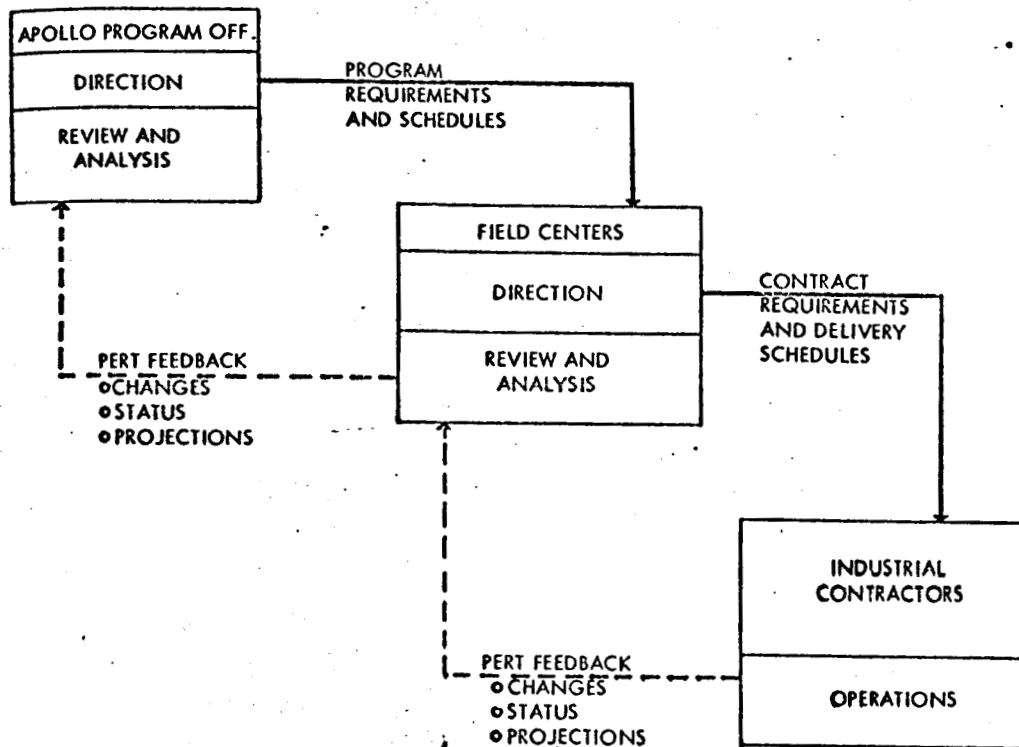


Figure 5
INTEGRATED SCHEDULING BASE

APD-4 is the Apollo Program Schedule and Hardware Planning Guidelines and Requirements. It originates in the Apollo Program Control Office. As such it provides scheduling information for the Apollo Program Director. The action called for in APD-4 is that all field centers are to implement the requirements of the directive effective with the issuance date and on a continuing basis thereafter. The purpose of APD-4 is to define the approved Apollo program schedule and hardware planning guideline requirements to be used as a baseline for detailed Apollo programming.¹¹

In addition to discussing the purpose, scope, procedures for change, and responsibilities involved in scheduling at the program manager level, APD-4J carries four attachments.

The first attachment covers the Apollo Manned Lunar Landing Program Baseline Plan. It describes in narrative significant developments affecting the scheduling of upcoming launches. Any changes in the preceding directive are highlighted. Hardware and launch complex assignments are summarized as in Figure 6. The final entry is the Apollo Launch Readiness Working Schedule as depicted in Figure 7.

The second attachment covers the Apollo schedule objectives, action required, and detailed working schedules. This attachment covers any changes in schedule objectives, i.e. acceleration or slippage of a series of sequential launches, and provides specifications on hardware to be used for each of several upcoming missions. That is, which booster is to be mated with a particular CSM and particular LM is designated. In addition broad directives are given as to which facilities are to be used in upcoming launches. Of particular importance are the launch schedules for upcoming missions which, in bar chart form, indicate to the field centers the activities necessary to provide integration of the centers to meet the launch date. An example is depicted in Figure 8.

The third attachment covers the Apollo hardware quantities and identification. These requirements are listed to provide forward planning information on which items and how many of each must be provided for the program.

¹¹ APD-4J Apollo Program Schedule and Hardware Planning Guidelines and Requirements, Washington, D.C., OASF, APO Program Control, November 20, 1968, p. 1. (restricted document).

HARDWARE AND LAUNCH COMPLEX ASSIGNMENT SUMMARY

SATURN V

<u>LV</u>	<u>CSM</u>	<u>LM</u>	<u>LAUNCH COMPLEX</u>			
			<u>LUT</u>	<u>FR</u>	<u>HB</u>	<u>PAD</u>
SA-501	017	LTA 10R	1	1	1	39A
SA-502	020	LTA 2R	2	2	3	39A
SA-503	103	LTA B	1	1	1	39A
SA-504	104	3	2	2	3	39B*
SA-505	106	4	3	3	2	39A
SA-506	107	5	1	1	1	39B
SA-507	108	6				39A
SA-508	109	7				39B
SA-509	110	8				39A
SA-510	111	9				39B
SA-511	112	10				39A
SA-512	113	11				39B
SA-513	114	12				39A
SA-514	115	13				39B
SA-515	115A	14				39A

*Pad A will be backup to Pad B for AS-504 Space Vehicle.

Figure 6

APOLLO LAUNCH READINESS WORKING SCHEDULE

20 NOV 68

[illegible]

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NOTE: AS-501 LAUNCHED 9 NOV 1967

APQ-1161

Figure 7

The final attachment lists the Apollo controlled milestones. These are categorized by field center and have specific dates for completion. As mentioned earlier, a change in these dates cannot be decided by the field center but must be approved at Headquarters by the Apollo Program Director. Examples of such controlled milestones are as follows:¹²

MSC Controlled Milestones

Deliver CSM 107 to KSC - AS-506	25 Jan. 69
Deliver CSM 108 to KSC - AS-507	18 Mar. 69
Deliver CSM 109 to KSC - AS-508	31 May 69
Deliver CSM 110 to KSC - AS-509	31 Jul. 69

MSFC Controlled Milestones

Deliver S-IC 5 to KSC	30 Nov. 68
Deliver S-IC 6 to KSC	17 Dec. 69
Deliver S-IC 7 to KSC	15 Apr. 69
Deliver S-IC 8 to KSC	16 Jun. 69

KSC Controlled Milestones

Launch Complex Operational Readiness

LC-39 LUT-3 FR-3, HB-2 ORD - Launch Veh.	15 Dec. 68
LC-39 LUT-3 FR-3, HB-2 ORD - BK-II CSM/LM	15 Jan. 69

These controlled milestones are but a few which are represented in the fourth attachment. They do provide an idea of the intercenter, interface ramifications of a controlled milestone and the reason why they must be met so that a launch will not be delayed.

Center Level Schedules

Thus far we have traced the key document flows associated with scheduling from the PAD, through the PDP, to APD-4. Each carries the scheduling plan to more specific levels of detail. At the center level additional schedules are developed and published in a series of volumes and books as follows:¹³

¹² Ibid., Attachment D

¹³ Apollo Program Development Plan, op. cit., p. 2-4.

Volume I represents the Level 1 Schedules Summary. It includes launch schedules, hardware quantities and deliveries required to support the launches, and individual mission charts for launches scheduled within the following year.

Volume II represents the schedules associated with the spacecraft at levels 2, 3, and 4. These levels correspond to project (spacecraft), primary systems (LM, CSM) and subordinate systems (reaction control system, environmental control system, electrical system, etc.) respectively.

Volume III is composed of four books (as of the January 1966 PDP). These include (1) the Saturn I, (2) the Saturn IB, (3) the Saturn V, and (4) engines. All schedules cover projects, primary systems, and subordinate systems (levels 2-4).

Volume V covers schedules on mission operations, flight operations, and ground operational support flight crew operations.

Volume VII covers schedules for construction of facilities and is divided into 6 books for the following: (1) KSC, (2) MSFC Huntsville, (3) MSFC Michoud, (4) MSFC Mississippi Test Facility, (5) MSC, and (6) MSFC various other locations.

Volume VIII covers schedules for space vehicles at KSC.

Each of these volumes contains dozens of schedules in bar chart form. The level of detail represented in these volumes is such that the key interfaces of center controlled milestones and headquarters milestones are evident. In addition a large number of supporting milestones are listed to provide planning and control visibility for the center program manager and his project managers. These supporting milestones can be changed at the center level and are therefore the dynamic factors which can be manipulated by center managers.

From this point on, the level of detail in scheduling is determined within the plants of the contractors and subcontractors in accordance with NASA procedures for supplying schedule information. An elaborate feedback network has been developed to inform managers of schedule status and provide a mechanism for making and transmitting schedule decisions. This network is discussed in Working Paper 15 and will not be elaborated upon at this point.

In summary we have traced the key document flows in scheduling beginning at the most general level with the Apollo Project Approval Document (PAD), moving from that point to the Apollo Program Development Plan (PDP), then on to the Apollo Program Directive 4 series (APD-4), through the field center schedules for levels 2, 3, and 4, to the final detail involved in contractor and subcontractor schedules. These schedules are related to the organizational levels within NASA as indicated in Figure 9.

Management System Elements

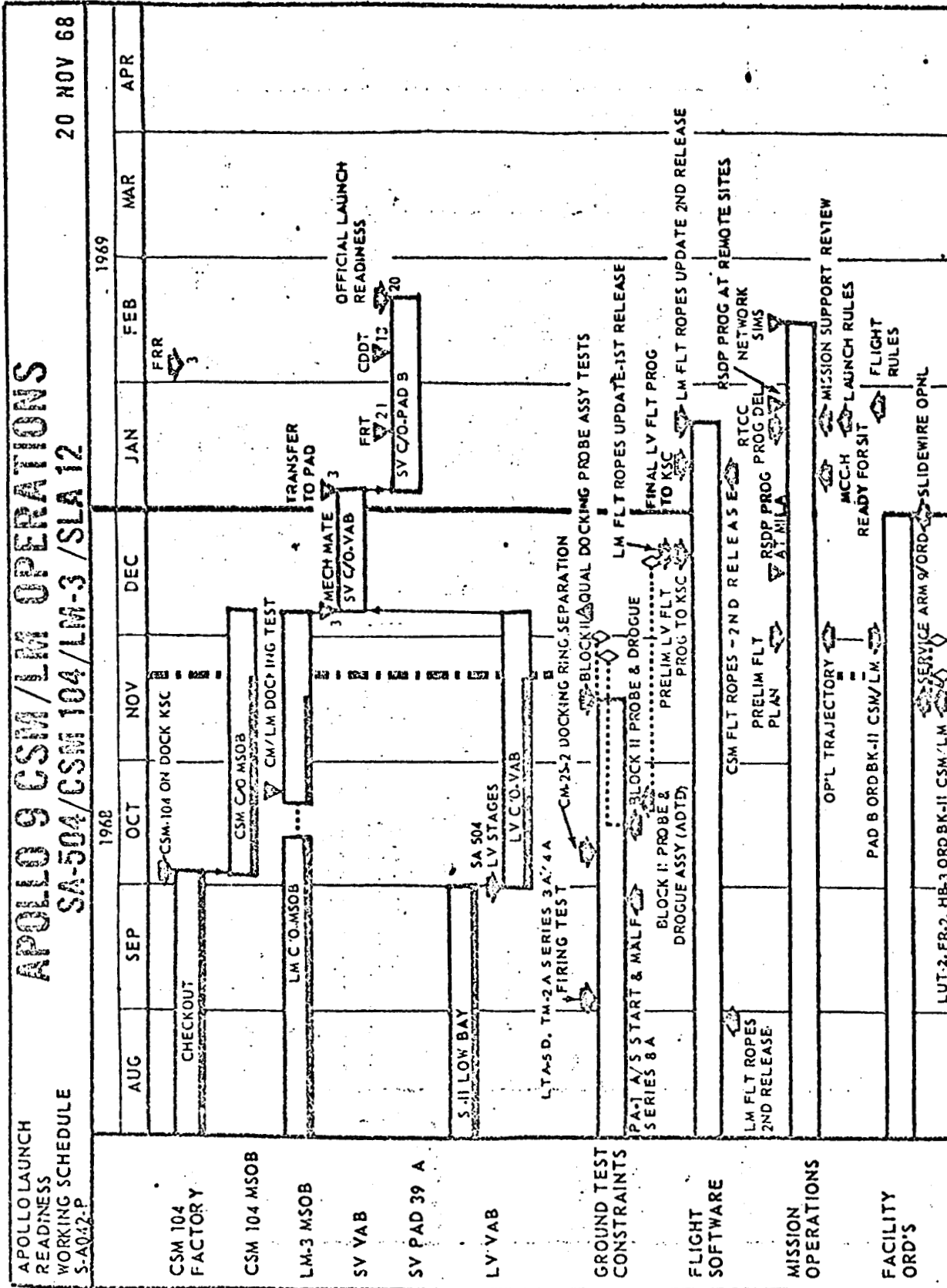
The management process as viewed from a classical management theory point of view is divided into several activities. These include planning, organizing, assembling resources, directing, and controlling. In general, traditional approaches to management start with the planning function in which three levels of plans are established.

The first level is the statement of objectives; those goals or targets toward which the organization directs its efforts. The second level concerns the formulation of policies or guides to action to reach the objectives. The third level involves procedures which detail the step-by-step activities which, hopefully, will insure action in accord with the policies.

In the administrative process of organizing two considerations are paramount; the definition of structural organizational relationships and the definition of administrative and operative relationships. In most cases this rests on principles of functionalism, unity of command, span of control, hierarchy, and so forth. The net result is often a rather stable organization which accepts change slowly.

Assembling resources involves the acquisition of the necessary money, manpower, materials, machines, facilities, and energy to accomplish the plans. Such efforts are usually divided functionally in traditional approaches to management.

Directing, in the traditional sense, implies that once the plans are laid,



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Figure 8

APOLLO PROGRAM MANAGEMENT

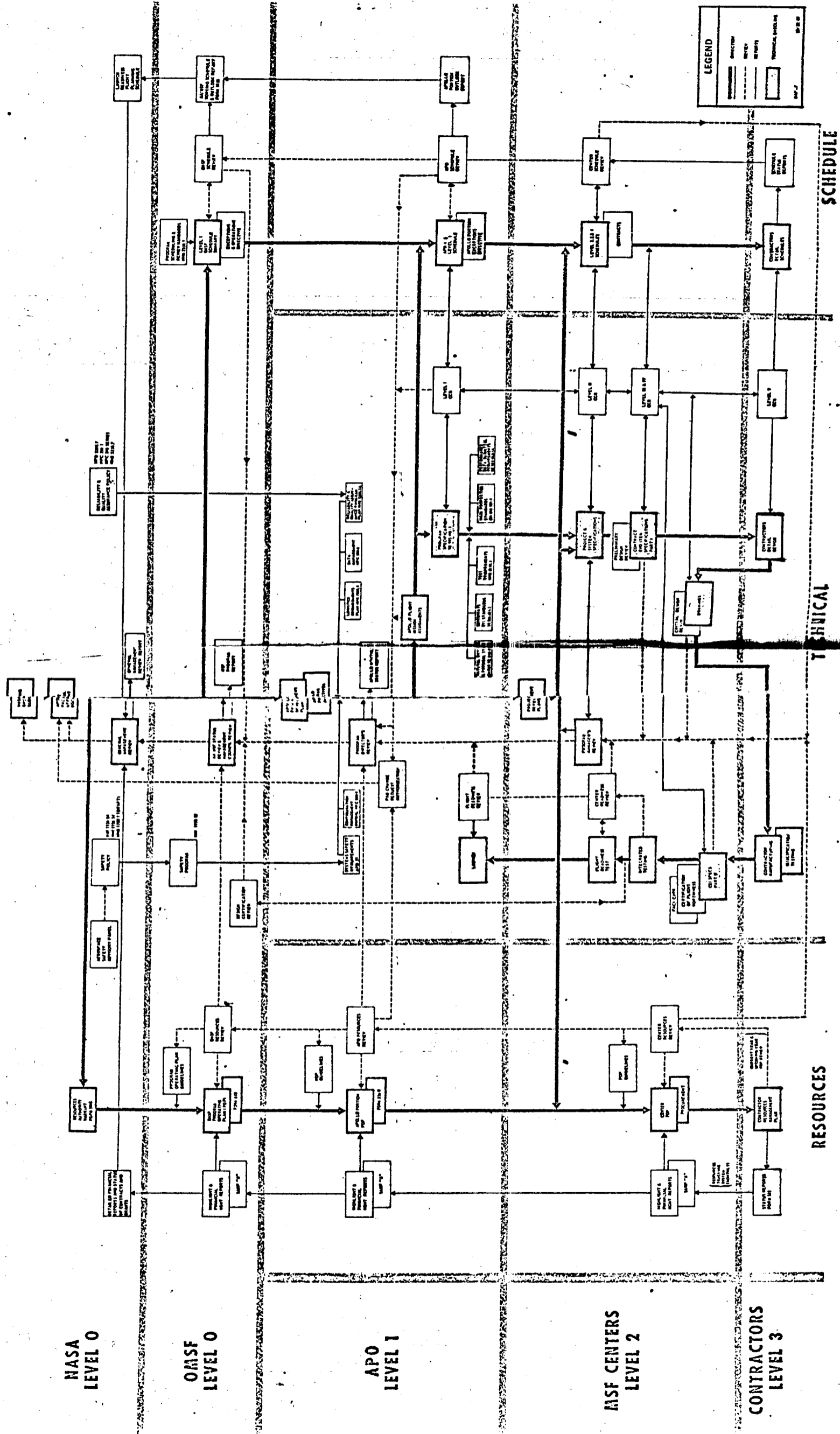


Figure 9

the organization developed, and the resources assembled, the entire operation can be put into motion through the issuance of orders via authority channels established in an orderly hierarchy.

Controlling implies that the results being achieved are compared to plans and, when deviations occur, the managers are held accountable for their results. If the results are unfavorable, then a course of action is initiated to acquire results more in conformance with the original plans.

This brief description of the classical or traditional approach to management lay out in skeletal form the basic elements involved in the management of most organizations. The emphasis will vary from one firm to another and the methods may vary also. Some managers plan carefully, others rarely take time to think through where they are going because they are so busy getting there. Some managers give directions as orders to subordinates, others rely on persuasion to achieve results. Some firms have elaborate control mechanisms while others are managed and controlled by "gut feel."

The purpose of setting forth the traditional approach is to establish a frame of reference for the management process as it applies in project management, particularly with reference to the Apollo Program. In this program a management process has been established which is composed of five parts, called management system elements. These basic elements are as follows:¹⁴

1. Requirements Definition
2. Requirements Amplification and Implementation
3. Management Information and Communication
4. Management Decision Process
5. Review and Evaluation of Management Effectiveness.

This approach to management changes the focus of managerial activities as compared to the traditional or classical approach. In project management heavy emphasis is placed on planning and control. The thoroughness of planning for a space mission surpasses that commonly found in industry. In addition the level of detail

¹⁴ NASA-Apollo Program Management, Apollo Program Office, OMSF, APO, Washington, D.C., December 1967.

to which planning is carried out is far more specific than is found in most firms.

Perhaps the most significant difference is the heavy concern in Apollo program management with the question of interrelationships among activities or interfaces as they are commonly tagged. In Apollo such interface planning and control is essential to accomplish a launch. When one considers that the activities of headquarters, three field centers, several prime contractors, and hundreds of subcontractors must fit together to achieve a launch, it becomes apparent why interface management is so critical in management system design.

The approach to control is also more detailed and thorough than is commonly encountered in industry. This is particularly evident in the management of hardware changes. An elaborate management system is used to control these changes known as configuration management. This subject is treated in another series of working papers. In addition to close control over changes, quality control practices in NASA are designed to yield phenomenal levels of reliability.

Associated with the emphasis on planning and control in project management an equal consideration is given to decision making and the management information system which supports the decision makers. Just as complex hardware production, assembly, and testing must be integrated for a successful launch, so also must the decisions made in all of the organizations involved be integrated.

To grasp the general management framework within which scheduling activities take place we shall briefly examine each of these five basic elements of the Apollo Program management system. A schematic depicting the organizational levels, feedback loops, and the functions of these elements appears in Figure 10.

Requirements Definition

"The first necessary step of the management process is the definition of the program requirements. These requirements form the baseline that lays the foundation for program management actions and provides the criteria against which program processes and changes are evaluated."¹⁵

¹⁵ Ibid., p. 4-4

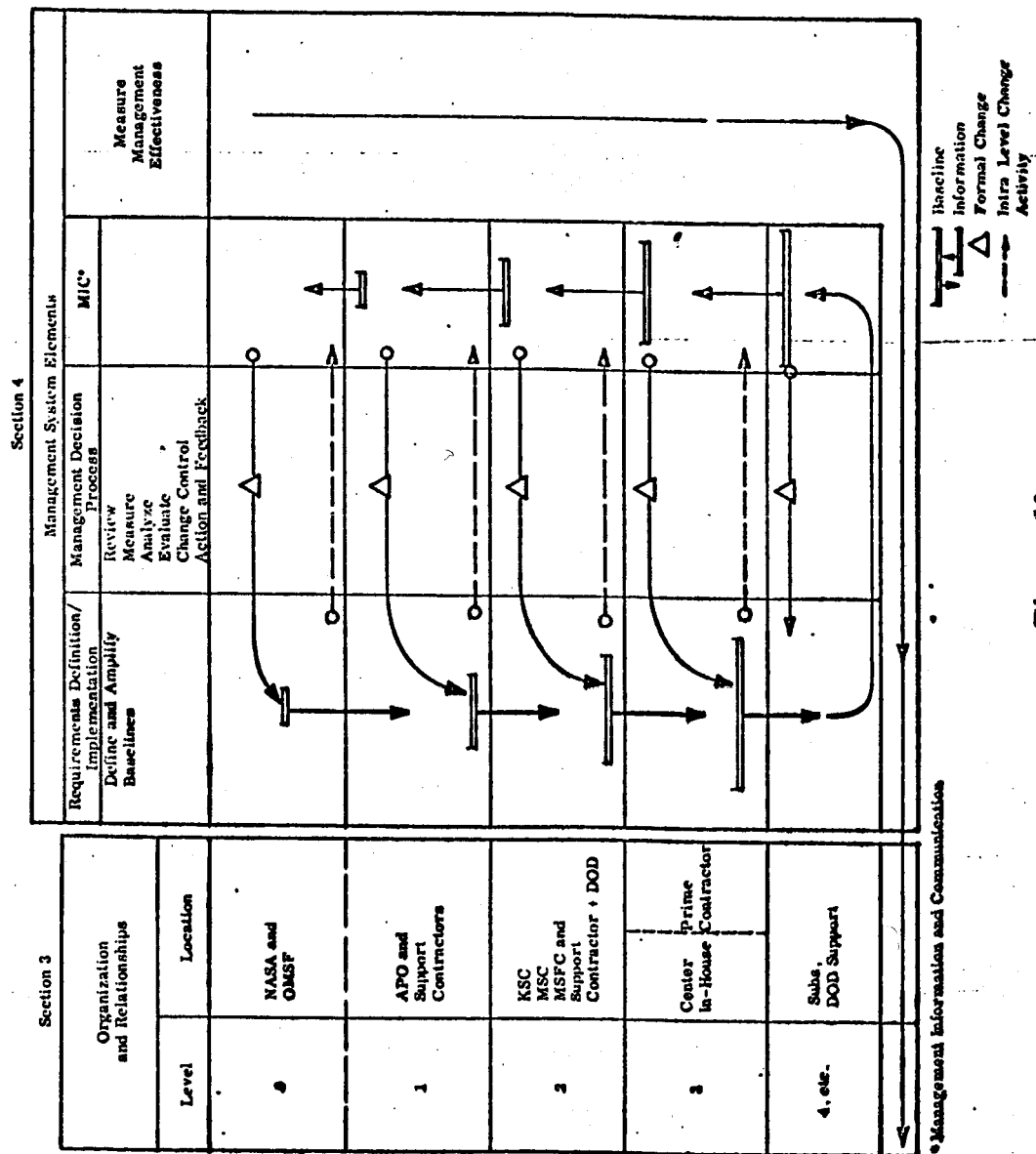


Figure 10

Management Direction, Response, Decision

The requirements established for the program are divided into three broad categories; management, technical, and mission. Within management, several areas are considered. These include program management, schedules, procurement management, configuration management, data management, funding and manpower requirements, logistics, facilities, and activation of launch site facilities and equipment.

Within the technical area consideration is given to reliability and quality assurance, technical description and systems engineering, the test program, and safety.

Within the mission area, plans must be made and requirements established for mission operations and mission training. These three broad areas are depicted with their subareas in Figure 11. Note that all of the areas have three dimensions of efficient project management involved with them; performance, cost, and schedules. The planning activities in each of these areas which yield the basic requirements for the program involve consideration of these three variables and a balance of such considerations in the development of requirements.

Of interest in the area of scheduling are several documents which have been established. One of these is the NASA PERT and Companion Cost System which specifies how scheduling should take place. Over time other scheduling plans have evolved as the complex situations requiring PERT yielded to less complex scheduling systems. A related document is the Program Scheduling and Review Handbook (SARF) which is designed to establish requirements for schedule status reporting.

A coding structure has been established to provide for uniform identification and classification of the work breakdown structure. This work breakdown structure, in turn, defines which activities will be separated out for scheduling attention.

Also involved in the management requirements definition area are key management requirements documents. These documents include the Apollo Project Approval Document (PAD), the Apollo Program Development Plan (PDP), and the Apollo Program Schedule and Hardware Planning Guidelines and Requirements (APD-4 series). Each of these documents is described in the preceding section of this paper with emphasis

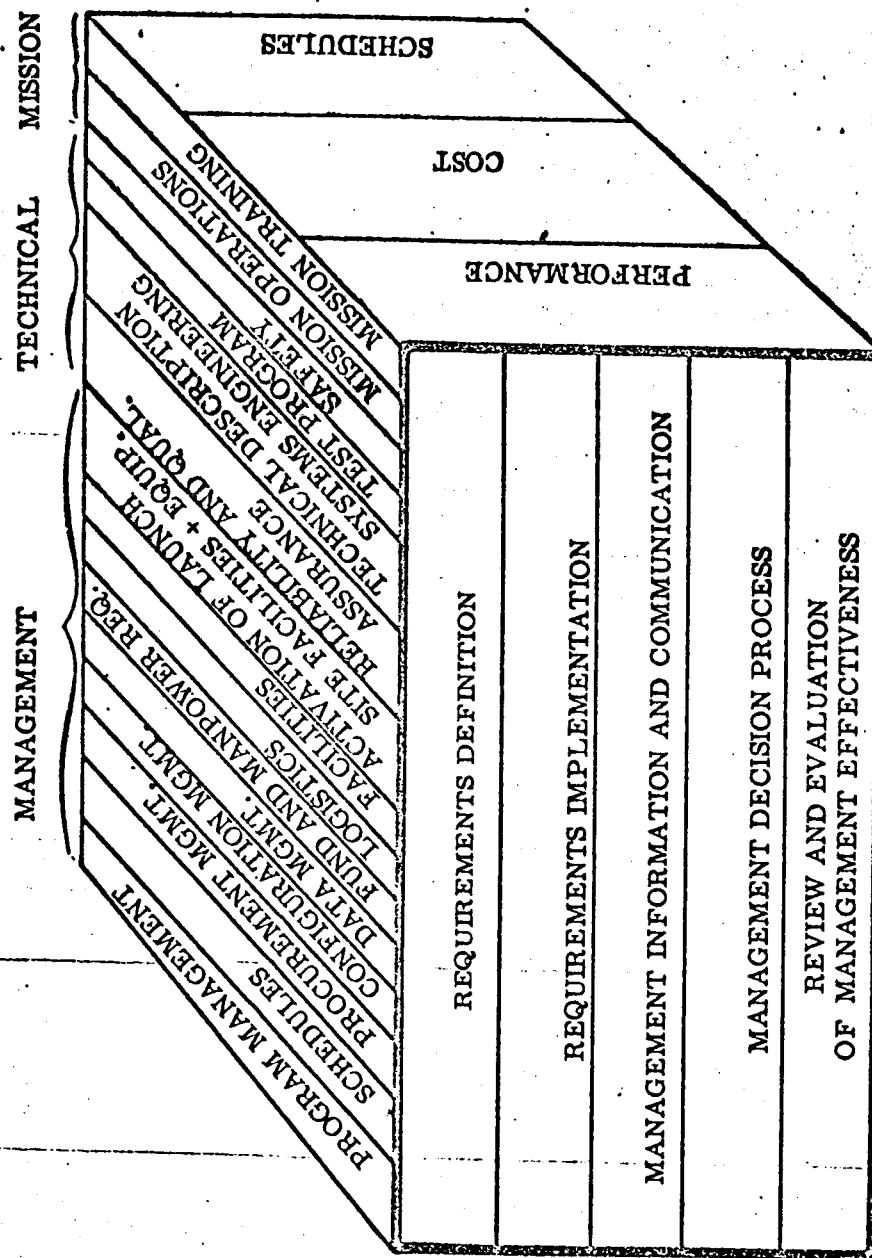


Figure 11

Management System Elements

on their role in scheduling. By scanning the contents of the PDP, however, it becomes clear that it covers all of the management, technical, and mission areas depicted in Figure 11, not just the scheduling area.

Other documentation in the area of establishing management requirements are procurement documents, contract work statements, and various Apollo schedules documents. A related document, associated with the financial side of management, but having relevance to scheduling is the Program Operating Plan (POP). The relationship of these documents within the NASA organization is portrayed in Figure 12.

Requirements Amplification and Implementation

"Requirements implementation is the process of converting requirements into assignments which direct people to act, schedules to be met or developed, and funds to be committed within the constraints established with respect to performance, cost and schedule."¹⁶

The requirements amplification and implementation element of the Apollo Program management system, in effect, is the parallel to the "directing" function of traditional management theory. It involves the following: the use of the NASA issuance system, the use of contracts and letters of technical direction, action items, and actual day-by-day direction.

The NASA issuance system is a requirements implementation media. "This system is used by all organizational elements of NASA Headquarters to promulgate management issuances governing matters within their delegated authority. Management issuances are written communications that prescribe, establish or define policy, organization, methods, procedures, or guidelines; or that contain information essential to effective administration of programs; or that contain authority or information that must be formally passed down through the various organization levels. The following are types of issuances in the NASA issuance system:

NASA Policy Directives are used for all statements of policy.

¹⁶ Ibid., p. 4-16.

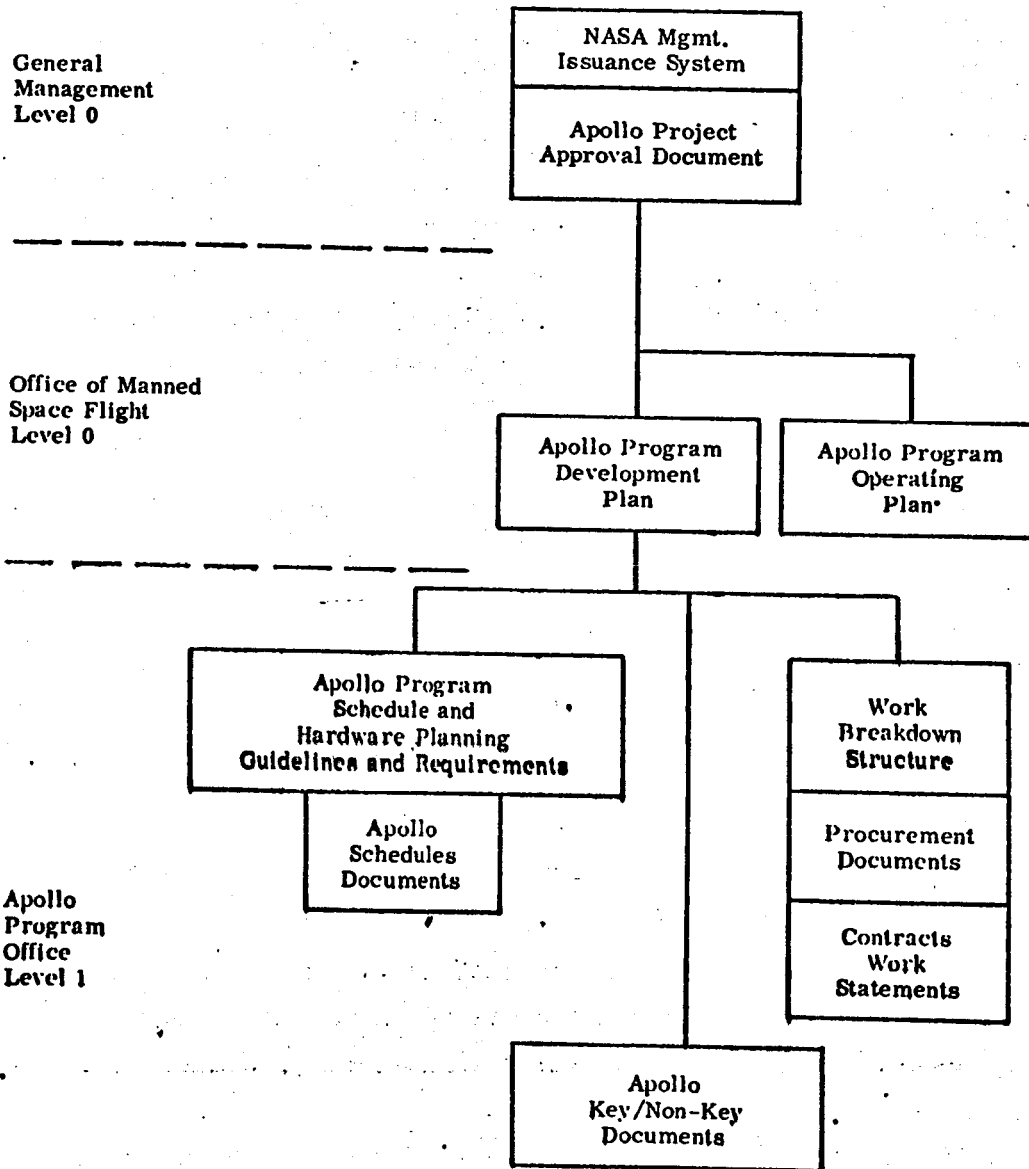


Figure 12
Key Management Requirement Documents

NASA Management Instructions are used to implement procedures and information of varying levels of detail and of a continuing nature.

NASA Notices are used by management for issuance of information of a temporary or one-time nature. Normally, cancellation occurs within six months from date of issue and in no case is it more than one year from issue date.

Complementary Manuals are used when specifically authorized by the Deputy Associate Administrator for Administration. Ordinarily, such complementary manuals are authorized only when there is a large amount of material of highly specialized matter."¹⁷

Although the NASA issuance system provides the vehicle for direction within NASA a second important element of requirements implementation as it affects those organizations outside the agency is the series of contracts and letters of technical direction.

"Contracts and associated work statements are a part of the requirements baseline and define the scope of work to be performed. However, once contracts are signed, they become instruments of implementation and contractors prepare detailed work plans to meet the contract requirements. Letters of technical direction transmitted through the contracting offices are the means of adding to or deleting from, or modifying the requirements baseline established by the contract."¹⁸

Action items are designed to amplify and implement requirements for the variety of task forces which operate during the life cycle of a program. Formal direction, the last item, is the commonly used authorization for change of specific requirements. These areas are depicted in Figure 13.

Management Information and Communication

In efficiently managing a task as complex as the Apollo program with so many people involved and dispersed over such a wide geographic area it is necessary to develop an

¹⁷ Ibid., Appendix D (For a more complete description see NASA Management Instruction NMI 1410-1.

¹⁸ Ibid., p. 4-16.

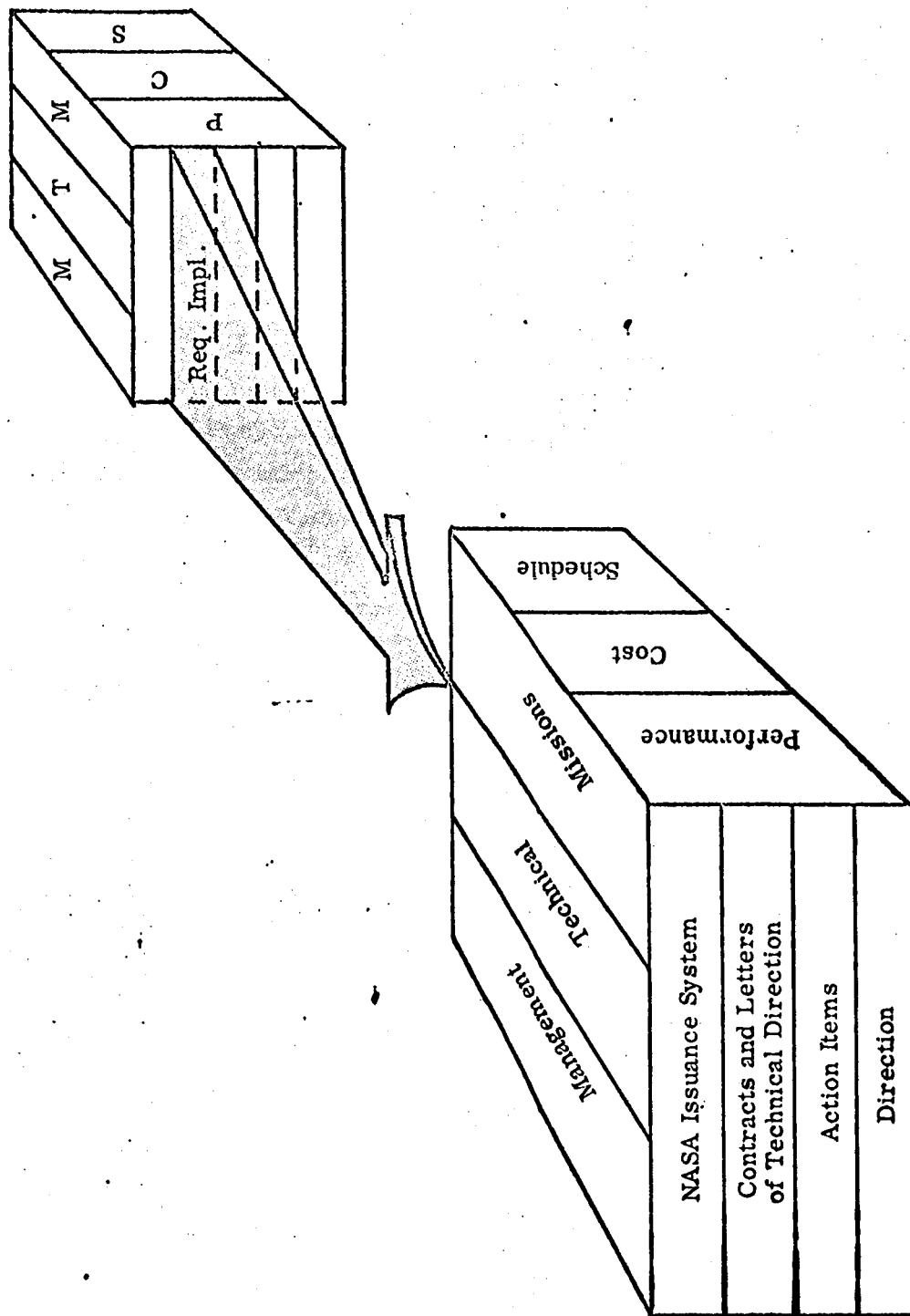


Figure 13
Program Requirements Implementation

elaborate management information system. Not only must this system capture all relevant data for decisions but it must also do it rapidly. The best example of such a system within NASA is the information system associated with the control of a space mission. It involves communications between KSC and MSC, information transmission through the world-wide tracking network, as well as data transmission to and from the spacecraft. All of this occurs in real time. An equally important, but less dramatic system is that which has been developed for Apollo program management.

"Visibility demands both effective communication and close working relationships between all management levels. This requires the establishment of logical reporting and communication requirements to fulfill defined information needs that tell how well each area of the program is being managed and how each area is progressing against the baseline plan."

"A number of techniques are used in Apollo to insure that actual and potential problems in technical performance, cost, and schedule are quickly and accurately identified and brought to the attention of the proper level of management for solution or decision. In a program as large and complex as Apollo, it is obviously impossible for one individual to know the exact status, in detail, of all the activities throughout the program. This is why the work breakdown structure is such an important management requirement. It permits the total task to be broken down into manageable portions and responsibility and authority to be assigned to competent individuals. Apollo management information and communication relates to the work breakdown structure and is handled in an integrated and disciplined manner to provide individuals at each level of management the visibility and data needed to direct and control the portion of the total program under their cognizance."¹⁹

The type of feedback which provides this visibility includes reviews, reports, plans, specifications, directives and instruction, statements of work, and personal liaison. These forms of feedback provide the standards and measures of performance with which managers can make those decisions which are required to keep the program moving successfully

¹⁹ Ibid., pp. 4-26-27.

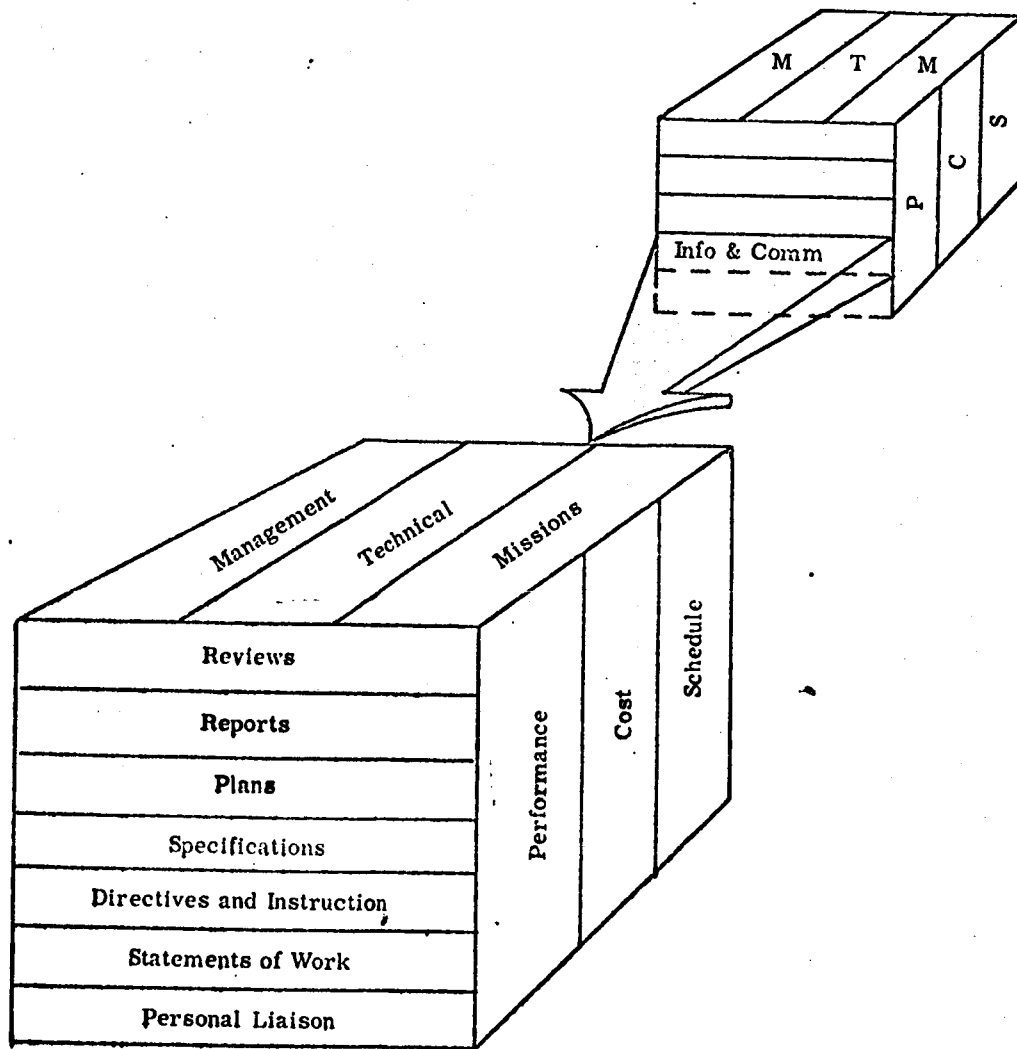


Figure 14
Management Information and Communication

toward its objectives. The relationship of these factors is shown in Figure 14.

"The heart of the Apollo management information and communication element with respect to formal documentation is the Apollo Data Management System. The basic concept of Apollo Data Management is that it gets the right data to the right person at the right time for the right cost. Additionally, only the minimum essential information is systematically acquired and the people who need it get it by the most direct means. Furthermore, in clearing house style new information needs are met, old information needs continue to be satisfied and when no longer required are purged."²⁰

Although the Apollo Data Management System provides a vehicle for accomplishing the above ends, it should be recognized that for effective project management there is no real substitute for information sources which are direct and relevant to the particular manager involved in a decision. These information channels cannot always be formalized because they are subject to change as critical problems change. For this reason they generally develop as effective informal information channels between the person with the need to know and those who can provide accurate, first-hand information.

Management Decision Process

"Requirements definition and implementation within the segments of the work breakdown structure and the constraints of cost, schedule, and performance cause people to perform, funds to be committed, and resources to be allocated. The management information and communication system assures that the right data gets to the right people at the right time to provide visibility at all levels of management such that the management decision process may then be effected. The management decision process is the fourth and most important element of the Apollo management system."²¹

In the decision process in industry a series of sequential steps are usually involved as follows:

1. Identification of a problem

²⁰ Ibid., p. 4-30.

²¹ Ibid., p. 4-37.

2. Separation of symptoms from causes of the problem
3. Gathering pertinent information about the causes
4. Development of alternatives to solve the problem
5. Analysis of the alternatives
6. Selection of one course of action and implementation of it
7. Follow up to see if the results correct the problem.

Most managers in industry follow this procedure or one closely related to it. In many cases, however, the procedure is highly informal and may reflect priorities or biases of particular managers with respect to one or more of the steps involved. For example, some managers are quick to spot problems but fail to separate symptoms from causes. In trying to cure the symptoms they wind up fighting brush fires which recur again and again. In other cases some managers lock on to a single alternative to solve a problem rather than taking the time to develop several alternatives. This habit often results in unimaginative decisions and thwarts the creativity of subordinates who may make no headway in presenting other alternative solutions. As another example of deficiencies of some managers in decision making is the case of the manager who after making a decision fails to follow up on it. If sufficient information feedback filters are at work in the organization to keep results from the manager, he may fall into the habit of assuming that once his decision is made that the problem is solved. In the ever changing environment of business this is rarely the case.

Because of these fairly common problems associated with decision making, NASA has taken a rather structured approach to the decision process. It includes procedures for assessment of the program status, formal review and evaluation techniques, action and feedback activities, and formal approaches to follow-up. The relationship of these activities to the management system elements is shown in Figure 15.

Decision making inherently involves selection of one course of action from among several alternatives. As this is the case it is apparent that priorities have a very significant bearing on the decisions which are reached. In industry such priorities vary according to the functional areas in which the decisions are made. For example,

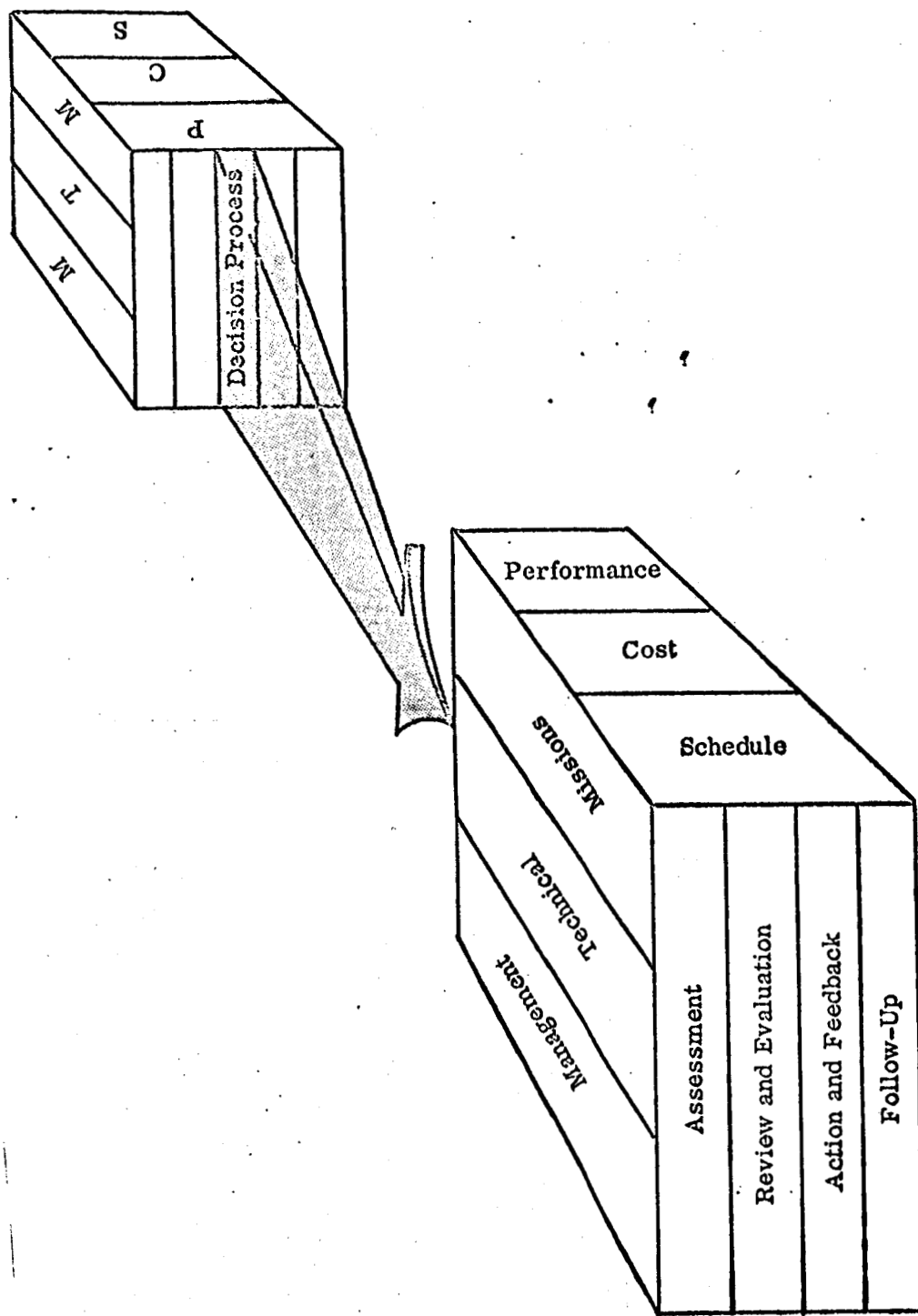


Figure 15
Program Management Decision Process

production managers strive for efficiency and productivity, marketing managers strive for increased sales volume, and financial managers look to increasing returns on investments to name but a few of the factors considered. These differences in priorities often result in suboptimization for the firm as a whole as each functional unit strives to achieve its ends.

In NASA, however, it is essential that all managers be cognizant of the primary priorities for the program and make decisions recognizing the rank order of these priorities.

"The basic NASA policy regarding manned flight is that nothing be done that will compromise the balance between crew safety and mission success, with crew safety being the primary consideration. This policy is expressed in the original Apollo specification:

'The primary considerations which must be weighed in the design and implementation of the Apollo system are listed below in order of descending priority:

- a. Crew Safety and Mission Success. Crew safety and mission success shall be the primary considerations in the design of the system. Crew safety is defined as the safe return of all crew members whether or not the mission is completed. Mission success is defined as the safe return of all crew members after a lunar landing.
- b. Schedule. Accomplishment of a manned lunar landing mission as early as possible, but before the end of 1969, is a national objective. Design approaches and decisions shall be made in recognition of this objective but not at the expense of confidence in crew safety or mission success.'

This policy has been and continues to be the guiding principle for decisions in the Apollo program."²²

The emphasis on crew safety has had an enormous effect on decisions in Apollo.

²² Ibid., p. 4-38-89.

Redundant systems have been incorporated in spacecraft to provide phenomenally high levels of reliability. As an example of what can happen when crew safety is jeopardized consider the effects of the program as a result of the AS-204 spacecraft fire which claimed the lives of three astronauts. The entire spacecraft was redesigned, numerous management methods were radically modified, organizational changes were made in short order, and the program itself was slowed until the problems could be resolved at a significant sacrifice to the schedule priority. Fortunately a lunar landing was accomplished in 1969 even with the delays encountered by the spacecraft fire.

It is also interesting to note that a subtle change in priorities occurs over the life cycle of a project. At the outset, the emphasis appears to be on technical performance as design and testing activities are undertaken. Schedule and cost considerations seem to follow technical considerations during this phase. As the project nears its assigned completion date then the schedule becomes very important and decision reflect the placement of higher priorities on this factor. To meet the schedule, crash programs are often undertaken at the sacrifice of cost priorities. Finally, as the program is phasing down, cost considerations receive a significant amount of attention which may lead to decisions to stretch the program to occupy the talents and skills assembled until a new program can be launched.

There are numerous reviews which are conducted to aid decision makers in the Apollo program. These reviews serve to "evaluate program progress and verify performance in terms of schedule, cost, and technical performance. These Program Reviews serve as a stimulant to management action rather than a "progress reporting" exercise. For each of the reviews, a single authoritative focal point (person) is designated who is sufficiently familiar with the total program to selectively design an agenda that focuses management attention on the problems that require resolution and action. The selection of speakers and subjects draws from the total complement of functional specialists and managerial staff in such a way that each problem is clearly defined, alternate solutions are presented in terms of relative impact on technical performance, schedules, and costs, and required management action or decision is clearly stated."²³

²³ Ibid., p. 4-41-42.

These reviews are carried out throughout NASA and in contractor plants. The feedback time is relatively short, particularly in the case of the Apollo Program Director's meeting which is held every morning. Other key reviews at the top management level include:

1. The Apollo Program Office Review
2. The Manned Spaceflight Program Status Review
3. Management Council Meeting
4. Deputy Administrator's Review

Although these reviews provide a formal method of assessment and set a framework for formal decision making, much of the important information moves through informal contacts. These informal contacts include "the personal conversations, the closed door sessions, and the "hot line" discussion of key program management personnel. Regardless of how scientific the approach to problem solving is and regardless of how sophisticated the management system and tools are, the program cannot be properly managed without the effective use of the "eyeball-to-eyeball" communication mode. The Apollo Program cannot and is not managed by people sitting at desks and in conference rooms reviewing program progress and problems and arriving at the right decisions at the right time. Intimate contact between the Program Director and the Center Program Managers is essential and is exercised to the utmost in feeding day-to-day problems up the line from the center and contractor levels and the necessary decisions back down to the level where they are required."²⁴

Review and Evaluation of Management Effectiveness

The last element of the Apollo management system is the review and evaluation of management effectiveness. This is necessary because such a large number of independent management teams are involved in the Apollo effort. To maintain overall management visibility of the contributions of each of these management teams, systems have been

²⁴ Ibid., p. 4-46.

developed to measure their effectiveness over time. Such measurement and review is carried out by NASA on a continuing basis.

"An evaluation of NASA centers and contractor's performance, both individually and on a comparative basis, requires that many factors be considered. The most important of these factors include: the type of contract, difficulty in design and manufacture of hardware, phase of development, and dependency on other contractor or government furnished hardware, software, and engineering decisions and different management techniques utilized by different NASA centers and contractors. Therefore, it is not practical or appropriate to measure one contractor or NASA center against another on an absolute one-to-one basis. A compatible technique of assessing competence is utilized in discussing NASA and contractor competence to meet Apollo goals based on cost, schedule, and technical performance indices."²⁵

These indices indicate which centers and contractors are ahead of schedule, on schedule, or behind schedule. Over time such indices provide the stimulus to management to improve operations and also highlight problems for NASA management. Other indices also reflect cost performance and technical performance. By gathering and posting this information frequently it becomes possible to monitor the program's progress and keep it moving forward in a balanced manner.

Review teams are activated to examine contractor activities in several areas:

1. Program planning and control.
2. Contracting, pricing, subcontracting, and purchasing.
3. Engineering.
4. Manufacturing.
5. Reliability and quality assurance.

"After completing the review, a verbal presentation is given by the review team to the NASA Associate Administrator for Manned Space Flight and to the contractor corporate and division management. Following the presentation, the findings and recommendations for

²⁵ Ibid., p. 4-54.

improvement are provided to the contractor for appropriate action and follow-up."²⁶

These reviews and evaluations serve to overcome a number of potential problems in the area of scheduling. These problems stem from a human tendency not to get excited about events far downstream in the future. Yet by overlooking minor slippages in today's schedules, the cumulate effect over time can be significant degrees of schedule slippage. The reviews serve to maintain the necessary schedule discipline and awareness required to get the job done on time.

²⁶ Ibid., p. 4-58.